ELECTRONIC DEVICES, METHODS, AND COMPUTER PROGRAM PRODUCTS FOR DETECTING NOISE IN A SIGNAL BASED ON AUTOCORRELATION COEFFICIENT GRADIENTS

BACKGROUND OF THE INVENTION

The present invention relates to signal processing technology, and, more particularly, to methods, electronic devices, and computer program products for detecting noise in a signal.

Wind noise may be picked up by a microphone used in devices such as mobile terminals and hearing aids, for example, and may be a source of interference for a desired audio signal. The sensitivity of an array of two or more microphones may be adaptively changed to reduce the effect of wind noise. For example, an electronic device may steer the directivity pattern created by its microphones based on whether the electronic device is operating in a windy environment.

In U. S. Patent Application Publication US 2002/0037088 by Dickel et al. and U.S. Patent Application Serial No. 10/295,968 by Stefan Gustavsson, a windy environment is detected by analyzing the output signals of two or more microphones.

SUMMARY OF THE INVENTION

According to some embodiments of the present invention, a noise component, such as wind noise is detected in an electronic device. A microphone signal is generated by a microphone. Autocorrelation coefficients are detected based on the microphone signal. Gradient values are determined from the autocorrelation coëfficients. The presence of the noise component in the microphone signal is determined based on the gradient values. Accordingly, some embodiments may detect wind noise in a microphone signal from a single microphone. In contrast, earlier approaches used signals from more than one microphone to detect wind noise.

In further embodiments of the present invention, various characteristics of the gradient values from the autocorrelation coefficients may be used to determine the presence of the noise component. The presence of the noise component may be determined based on the smoothness of the gradient values. For example, the

determination may be based on whether a rate of change of the gradient values satisfies a threshold value.

In other embodiments, the determination may be based on when the gradient values satisfy a threshold value. In still other embodiments, sampled values of the microphone signal may be generated that are delayed by a range of delay values. Autocorrelation coefficients may be generated based on the delayed sampled values of the microphone signal. The presence of a noise component may be determined based on whether the gradient values are about equal to a threshold value within a subset of the range of delay values. The determination may be based on whether the gradient values are substantially zero for delay values that are substantially non-zero. The determination may additionally, or alternatively, be based on whether the gradient values have a zero crossing for delay values that are substantially non-zero.

Although described above primarily with respect to method aspects of the present invention, it will be understood that the present invention may be embodied as methods, electronic devices, and/or computer program products.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram that illustrates a mobile terminal in accordance with some embodiments of the present invention.

Figure 2 is graph of autocorrelation coefficient gradients as a function of sample delay values for wind conditions and no-wind conditions.

Figure 3 is a block diagram that illustrates a signal processor that may be used in electronic devices, such as the mobile terminal of **Figure 1**, in accordance with some embodiments of the present invention.

Figure 4 is a flowchart that illustrates operations for detecting noise in a microphone signal in accordance with some embodiments of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within

the spirit and scope of the invention as defined by the claims. Like reference numbers signify like elements throughout the description of the figures. It should be further understood that the terms "comprises" and/or "comprising" when used in this specification are taken to specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

The present invention may be embodied as methods, electronic devices, and/or computer program products. Accordingly, the present invention may be embodied in hardware and/or in software (including firmware, resident software, micro-code, *etc.*). Furthermore, the present invention may take the form of a computer program product on a computer-usable or computer-readable storage medium having computer-usable or computer-readable program code embodied in the medium for use by or in connection with an instruction execution system. In the context of this document, a computer-usable or computer-readable medium may be any medium that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The present invention is described herein in the context of detecting wind noise as a component of a microphone signal in a mobile terminal. It will be understood, however, that the present invention may be embodied in other types of electronic devices that incorporate one or more microphones, such as, for example automobile speech recognition systems, hearing aids, etc. Moreover, as used herein, the term "mobile terminal" may include a satellite or cellular radiotelephone with or without a multi-line display; a Personal Communications System (PCS) terminal that may combine a cellular radiotelephone with data processing, facsimile and data communications capabilities; a PDA that can include a radiotelephone, pager, Internet/intranet access, Web browser, organizer, calendar and/or a global positioning system (GPS) receiver; and a conventional laptop and/or palmtop receiver or other appliance that includes a radiotelephone transceiver.

It should be further understood that the present invention is not limited to detecting wind noise. Instead, the present invention may be used to detect noise that is relatively correlated in time.

Referring now to **Figure 1**, an exemplary mobile terminal **100**, in accordance with some embodiments of the present invention, comprises a microphone **105**, a keyboard/keypad **115**, a speaker **120**, a display **125**, a transceiver **130**, and a memory **135** that communicate with a processor **140**. The transceiver **130** comprises a transmitter circuit **145** and a receiver circuit **150**, which respectively transmit outgoing radio frequency signals to, for example, base station transceivers and receive incoming radio frequency signals from, for example, base station transceivers via an antenna **155**. The radio frequency signals transmitted between the mobile terminal **100** and the base station transceivers may comprise both traffic and control signals (*e.g.*, paging signals/messages for incoming calls), which are used to establish and maintain communication with another party or destination. The radio frequency signals may also comprise packet data information, such as, for example, cellular digital packet data (CDPD) information. The foregoing components of the mobile terminal **100** may be included in many conventional mobile terminals and their functionality is generally known to those skilled in the art.

The processor **140** communicates with the memory **135** via an address/data bus. The processor **140** may be, for example, a commercially available or custom microprocessor. The memory **135** is representative of the one or more memory devices containing the software and data used by the processor **140** to communicate with a base station. The memory **135** may include, but is not limited to, the following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM, and may be separate from and/or within the processor **140**.

As shown in **Figure 1**, the mobile terminal **100** further comprises a signal processor **160** that is responsive to an output microphone signal from the microphone **105**, and is configured to generate one or more output signals that are representative of whether the mobile terminal is in a windy environment or in a no-wind environment. The memory **135** may contain various categories of software and/or data, including, for example, an operating system **165** and a wind detection module **170**. The operating system **165** generally controls the operation of the mobile terminal. In particular, the operating system **165** may manage the mobile terminal's software and/or hardware resources and may coordinate execution of programs by the processor **140**. The wind detection module **170** may be configured to process one or more

signals output from the signal processor **160**, which indicate whether the mobile terminal **100** is in a windy environment or a no-wind environment, and to selectively use, and/or modify the use of, one or more noise suppression algorithms and/or sound compression algorithms based on the wind or no-wind environment indication. Accordingly, the wind detection module **170** may operate to reduce the effect of a wind component in the microphone signal from the microphone **105**.

Referring now to **Figure 3**, an exemplary signal processor **300** that may be used, for example, to implement the signal processor **160** of **Figure 1** will now be described. The signal processor **300** comprises a delay chain **305** having *N* delay elements, an autocorrelation unit **310**, a gradient unit **315**, and a wind detector **320** that are connected in series to form a system for detecting the presence of a wind component in a microphone signal.

The delay chain **305** is responsive to samples of a microphone signal at different times, delays the samples by delay values, and provides the samples of the microphone signal, the sample times, and the delay values to the autocorrelation unit **310**. In some embodiments of the delay chain **305**, the microphone signal is delayed by delay values that are in a range that extends above and below zero (i.e., positive and negative delay values). The delay chain **305** may weight the samples, such that newer samples are weighted greater than older samples. If the microphone signal is given by s and the number of delay elements is N, then the autocorrelation unit **310** may generate autocorrelation coefficients $R()$ at delay k according to Equation 1 below:

$$R(k) = \frac{1}{N-k} \sum_{n=1}^{N-k} s(n)s(n+k) \qquad \text{Equation 1}$$

The gradient unit **315** generates gradient values from the autocorrelation coefficients. The gradient values are based on how the autocorrelation coefficients change relative to the delay values and/or time values for the sampled microphone signal (e.g., slope associated with adjacent autocorrelation coefficients).

Figure 2 illustrates example graphs of experimental data that was developed by subjecting a microphone to windy environment and no-wind environment inside and outside of a laboratory. The graphed curves represent gradient values that have been formed from the autocorrelation coefficients of the microphone signal versus

delay values. Curves **200a-b** were developed from the microphone signal in a no-wind condition (i.e., the microphone signal did not have a wind component). In contrast, curves **210a-b** were developed from the microphone signal in a wind condition (i.e., the microphone signal had a wind component).

As shown in **Figure 2**, the curves **200a-b** and **210a-b** demonstrate different characteristics based upon whether the microphone signal has a wind component. For example, although the gradient values for curves **200a-b** and **210a-b** change sign (i.e., change from positive to negative and/or vice-versa) by crossing the zero axis (zero crossing) for a substantially zero delay value, the curves **200a-b** (no wind component) also have zero crossings at some substantially non-zero delay values. For example, curves **200a-b** have zero crossings at delay values between about -125 and about -100 and between about 50 and about 75. The gradient values for curves **200a-b** also have substantially higher peaks near, for example, the zero delay value compared to the gradient values for curves **210a-b**. The gradient values for curves **210a-b** are also smoother over a range of delay values (i.e., smaller rate of change) compared to the gradient values for curves **200a-b**.

According to some embodiments of the present invention, the wind detector **320** determines whether the microphone signal includes a wind component based on the gradient values from the gradient unit **315**. The determination may be based on whether the gradient values pass through a known threshold value within a subset of the range of the delay values. For example, the threshold value may be zero and the subset of the range of the delay values may have substantially non-zero values, so that a zero crossing by the gradient values may indicate the presence of a wind component in the microphone signal. The known threshold value may be a non-zero value to, for example, compensate for bias in the gradient values and/or to change the sensitivity of the determination relative to a threshold amount of the wind component in the microphone signal.

The determination by the wind detector **320** may also, or may alternatively, be based on when the gradient values satisfy a threshold value. The threshold value may, for example, comprise positive and negative threshold values that are selected so that when one or both of the threshold values are exceeded by the gradient values, a wind component is determined to be in the microphone signal. For example, as illustrated in **Figure 2**, the gradient values of the curves **200a-b** have substantially larger values

than those of the curves **210a-b**, such that the wind detector **320** may compare the gradient values in a region near, for example, the zero delay to one or more threshold values to identify the presence of a wind component.

The determination by the wind detector **320** may also, or may alternatively, be based on the smoothness of the gradient values. For example, the determination may be based on when a rate of change of the gradient values relative to corresponding delay values and/or time satisfies one or more threshold values. For example, as illustrated in **Figure 2**, the curves **210a-b** are substantially smoother over the delay values than the curves **200a-b**. Curves **200a-b** exhibit substantially more rapid fluctuation of gradient values than those of the curves **210a-b** over corresponding delay values, so that the wind detector **320** may compare the gradient values in a region near, for example, the zero delay to one or more threshold values to identify the presence of a wind component.

The result of the determination by the wind detector **320** may be provided to a processor, such as the processor **140** of **Figure 1**, where it may then be processed by the wind detection module **170** of **Figure 1**.

For purposes of illustration only, **Figure 3** illustrates components that may be used to determine the presence of a wind component in a microphone signal based on the gradient of the autocorrelation coefficients. It should be understood that another set of components corresponding one or more of the delay chain **305**, the autocorrelation unit **310**, the gradient unit **315**, and the wind detector **320** may be provided to determine the presence of a wind component in a microphone signal from another microphone. In this manner, the present invention may be extended to embodiments of electronic devices comprising one or more microphones. However, some embodiments may detect wind noise in a microphone signal from a single microphone. In contrast, earlier approaches used signals from more than one microphone to detect wind noise, which can increase the complexity of the associated circuitry and increase the number of components that are needed to detect wind noise.

Although **Figure 3** illustrates an exemplary software and/or hardware architecture of a signal processor that may be used to detect wind noise in sound waves received by an electronic device, such as a mobile terminal, it will be understood that the present invention is not limited to such a configuration but is intended to encompass any configuration capable of carrying out the operations

described herein. For example, the operations that have been described with regard to **Figure 3** may be performed at least partially by the processor **140**, the signal processor **160**, and/or other components of the wireless terminal **100**.

Reference is now made to **Figure 4** that illustrates the architecture, functionality, and operations of some embodiments of the mobile terminal **100** hardware and/or software. In this regard, each block represents a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that in other implementations, the function(s) noted in the blocks may occur out of the order noted in **Figure 4**. For example, two blocks shown in succession may, in fact, be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending on the functionality involved.

With reference to **Figure 4**, operations begin at block **400** where autocorrelation coefficients are determined for a microphone signal, such as a signal that is output by microphone **105** of **Figure 1**. At block **405**, gradient values are determined from the autocorrelation coefficients. A determination is then made at block **410** whether the gradient values are substantially zero (e.g., zero crossing) for substantially non-zero delay values. The determination at block **410** may alternatively include comparing the gradient values to a non-zero threshold value, as was previously described with regard to the wind detector **320** of **Figure 3**. If the gradient values are substantially zero, then a determination may be made at block **415** that a wind component is included in the microphone signal. If however, the gradient values are not substantially zero, at block **410**, a determination may be made at block **420** as to whether the gradient values change more than a threshold amount for corresponding delay values and/or time, and if they do, a determination may be made at block **415** that a wind component is included in the microphone signal. Otherwise at block **420**, a determination may be made at block **425** as to whether the gradient values exceed a threshold amount, and if they do, a determination may be made at block **415** that a wind component is included in the microphone signal, or otherwise a determination may be made at block **430** that a wind component is not included in the microphone signal. In other embodiments, various sub-combinations of blocks **410**, **420**, and **425** may be used to detect the presence or absence of wind.

In some embodiments of the present invention, hysteresis may be used, for example, in block **415** and/or block **430**, such that a wind component is and/or is not detected unless the conditions of blocks 410, 420, and/or 425 are met and/or not met for a known number of gradient numbers, delay values, and/or time. According, the sensitivity of a wind detector to a brief presence of a noise component in a microphone signal may be adjusted.

Computer program code for carrying out operations of the wind detection program module **170** and/or the signal processor **160** discussed above may be written in a high-level programming language, such as C or C++, for development convenience. In addition, computer program code for carrying out operations of the present invention may also be written in other programming languages, such as, but not limited to, interpreted languages. Some modules or routines may be written in assembly language or even micro-code to enhance performance and/or memory usage. It will be further appreciated that the functionality of any or all of the program and/or processing modules may also be implemented using discrete hardware components, one or more application specific integrated circuits (ASICs), or a programmed digital signal processor or microcontroller.

Although **Figures 1, 3, and 4** illustrate exemplary software and hardware architectures that may be used to detect wind noise in a signal received by an electronic device, such as a mobile terminal, it will be understood that the present invention is not limited to such a configuration but is intended to encompass any configuration capable of carrying out the operations described herein. Accordingly, many variations and modifications can be made to the preferred embodiments without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present invention, as set forth in the following claims.